ELISE, a Code For Intensity Dependent Effects

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Abstract

The ELISE code described in this paper computes many of the intensity dependent effects of interest to the builder of a small electron storage ring.

Introduction

ELISE (Electron ring Limits on Intensity, Stability, and Emittance) is a program, developed largely for the author's own use, which duplicates many of the functions provided by the more general program ZAP [1] developed by the Berkeley group. The motivation for the code was to provide an interactive system for quick answers that could by used during accelerator commissioning. A lattice program, IDA[2], developed earlier by the author while at Brookhaven National Laboratory, provides a good model of the type of user friendly interaction that would be desireable in such a code.

General properties of the code

ELISE runs interactively on an IBM-PC. Like the most recent versions of IDA, it is written in Turbo Pascal, version 5.0. [3] It provides calculations of:

1. Bunch lengthening due to microwave instability.
2. Beam size growth due to intrabeam scattering.
3. Lifetimes from Coulomb scattering, bremsstrahlung, and the Touschek effect.
4. Threshhold currents and growth rates for the simplest modes of longitudinal coupled bunch instability.
5. Threshhold currents and growth rates for the simplest modes of transverse coupled bunch instability.

There are some limitations to the applicability of the code.

1. Only electron rings are considered.
2. The machine lattice data and focusing functions must be available in the form of an IDA data file, i.e. only lattices modeled by IDA can be used.
3. All buckets of the rf are assumed equally populated.
4. The Wang formalism is used for coupled bunch instabilities.
5. If the lattice has many elements, the intrabeam scattering calculations take a long time.
6. If the rf harmonic is large, the coupled bunch instability calculations are time consuming.

At each stage of an ELISE session, a command line or menu type list shows which ELISE options can be invoked. Each is activated by a single keystroke. There is no need of HELP functions and, after an initial tutorial, little need for off-line documentation. All of the input is also interactive, i.e. windows or prompts on the screen request the user to type in parameters as needed. In cases where many numbers are needed, as for example the apertures around the lattice, provisions are made for saving and getting the data from disc files. Where applicable, results are shown as graphs but, in all cases, tabulated numbers are also provided. At the end of a session, a file (for later printing off-line) can be created which includes a complete summary of all input and all results. Also, the parameters can be written as input files for ZAP in order that results can be checked.

Start-up and microwave instability calculation

In a typical session, assuming the lattice of the electron ring of interest has been modeled with IDA, an initial dialogue permits one to load the data base of that ring into the ELISE memory space. Then one has options for:

1. proceeding with the microwave instability problem.
2. entering a portion of IDA to reset the energy, rf volts, rf frequency, or chromaticity.
3. getting data for a different ring.
4. quitting the ELISE system.

If one chooses the microwave case, one is prompted for a beam current. (One can typically choose about twice the operating beam current here). A graph then shows the bunch length as a function of total beam

1 ZAP User's Manual , M.S. Zisman et.al., LBL-21270 (1986)
2 Interactive Design of Accelerators, IDA , Mark Q. Barton, BNL-40011(1987)
3 Turbo Pascal is a trademark of Borland International, 1800 Green Hills Road, P.O. Box 660001, Scotts Valley, CA 95066-0001

current for impedances Z/n of 2, 5, 10, and 20 Ohms. A window then prompts for the actual current and impedance to use for further calculations. The graph is repeated with the chosen conditions. This calculation is based on the simple theory of microwave instability and does not include SPEAR scaling.

Intra-beam scattering

The next option is for a calculation of the beam size growth due to intrabeam scattering. A full Mtingwa-Bjorken[4] calculation is done. The lattice functions at the beginning of each element (as tabulated by IDA) are used throughout the element rather than an estimate of appropriate averages of the functions through the length of the element. Once the diffusion rates are calculated, an extrapolation is made to determine at what beam size and energy spread the radiation damping is in equilibrium with the diffusion due to intrabeam scattering and quantum excitation. The energy spread is constrained to not fall below the microwave instability limits computed in the first option. Using the extrapolated beam sizes, the intrabeam scattering diffusion is re-computed; these iterations continue until a balance is achieved. Surprisingly, the calculation only takes a few seconds on an IBM PS/2 model 80 with math coprocessor for a lattice with a dozen elements.

At this point, an option becomes available to draw graphs of the beam emittance and energy spread as a function of energy. The user is warned that if this option is exercised, the calculation just described will be done eleven times. If one does not want to wait that long, one can by-pass the option and proceed directly to the lifetime option. If the option is exercised, the user is prompted for the energy range for which the computations are to be done. The complete calculation (including proper scaling of all variables and repeat of the microwave instability limit) is done at eleven points equally spaced in the specified energy region. Graphs (simple straight lines connecting the computed points) show the horizontal emittance and energy spread as a function of energy.

Life times

Coulomb scattering, bremsstrahlung, and the Touschek effect are considered in the lifetime calculations. A very convenient screen editor allows the user to enter most of the common gas pressures just as they are detected by the RGA's on the ring. A special option allows the user to edit the local ring apertures. These can be saved as a disk file for future reference so that one does not need to re-enter aperture data each time a given lattice is studied. The screen showing apertures also shows the momentum aperture available at each point in the lattice. One notes that, as a physical aperture is changed at one point in the lattice, that might affect the momentum aperture available at another. This comes about because a sudden energy shift causes an increase (or decrease) of the betatron amplitude through the dispersion function and there may not be enough aperture at another point in the ring for the betatron oscillation. This is important for a proper calculation of the bremsstrahlung and Touschek lifetimes. ELISE uses these apertures following the recipe described in Ref. 1. [5]

The lifetimes are combined to give an overall lifetime; this is interpreted as the inverse of the logarithmic decay rate since the gas scattering effects are the $1/e$ lifetimes and the Touschek lifetime is a half-life.

If, earlier in the intrabeam scattering calculations, the graph of beam sizes versus energy was exercised, then it is trivial to compute the lifetimes as a function of energy and, indeed, that option is now available to the user. Also, one can view a graph of Touschek lifetime versus rf volts. In principle, this is trivial unless the momentum excursions are limited by the aperture rather than the rf bucket. The calculations for this graph take a long time because a complete microwave instability and intrabeam scattering calculation is done at each rf amplitude.

Longitudinal coupled bunch instability

Following the lifetime calculations, one has the option of computing threshhold currents and growth rates for coupled bunch instabilities. On entering this option, one is first presented with a window requesting entry of higher order mode data. With a single keystroke, "A" for example, one can add a mode. Another window appears prompting for the frequency (in MHz), shunt impedance (in MegOhms for longitudinal modes or MegOhms per meter for transverse modes) and Q factor. Note that transverse and longitudinal modes are on the same screen and there is another field where one enters "L" or "T" to distinguish between them. Up to twenty modes can be entered. There is another field which is either "A" or "D" indicating active or disabled. This permits the user, later, to turn modes off and on, one by one, to help identify the source of a given problem. On the mode editing page are also options for

4 J.Bjorken and S.K.Mtingwa, Particle Accelerators , 115(1983)
5 ZAP User's Manual, op.cit., p.173

saving and recalling the mode data on disc so this editing procedure is not necessary for each new run.

When the mode data appear in order, the user is next presented two windows for entering the type of wall material and the effective aperture radius for the flow of image charges. On completion of these entries, ELISE presents the user with a table of growth rates and frequency shifts for the dipole mode ($a = 1$ in ZAP notation) longitudinal coupled bunch instability. Only the five modes with fastest growth rate and five modes with highest magnitude of the real part of the frequency shift are tabulated. The format of the results are virtually the same as used by ZAP except that, in the unstable cases, the results in the first table are shown in red (assuming a color monitor) and, instead of the code letter used by ZAP for stable or unstable, a threshhold current is computed based on a calculation of the dispersion relation using the actual real and imaginary parts of the frequency shift. At some current, the growth rate will equal the radiation damping rate. The larger of this current and the result of the solution to the dispersion relation is tabulated as the threshhold current.

At this point, the user can return the higher order mode page or the windows describing the vacuum chamber walls to investigate the effects of individual modes, etc. Another option (called "Toggle Causes") permits the user to individually turn on or off the broadband impedance, the resistive wall effect, all of the cavities, or the space charge term. One can quite quickly, in this format, investigate this type of coupled bunch instability. Note that the Wang[6] formulation is used and only the $a = 1$ case is considered.

Transverse coupled bunch instability

The user next has the option of exploring $a = 0$ and $a = 1$ transverse coupled bunch modes. The format follows that of the longitudinal modes. Appropriate windows prompt the user for additional information needed, the betatron tune spread and which transverse plane is to be considered. Where the chromaticity is needed, the value from the original IDA data base is used. Like the longitudinal case, there are options here to return to any of the various settings and change them. This includes the dynamic variables tune spread and chromaticity. Another option is to restart all of the coupled bunch calculations but without reverting back to the beginning of the ELISE options.

Finishing the run

On completion of the coupled bunch calculations, the user is given options for:

1. Writing a file for off-line printing which gives a hard-copy record of the entire ELISE session.
2. Writing a set of files for running a batch run with ZAP.
3. Returning to the beginning of ELISE for a new run.
4. Quitting.

Conclusions and acknowledgement

The author has found that the goals for writing this code have been completely achieved. He wishes to acknowledge the enormous help he has received from the ZAP manual. This book should be viewed as the model for computer code documentation. It contains explicit instructions on how to use the code, an excellent theoretical overview of what is in the code, and an extensive bibliography.

[6] J.M. Wang, "Longitudinal Symmetric Coupled Bunch Modes" BNL-51302, December 1980, unpublished